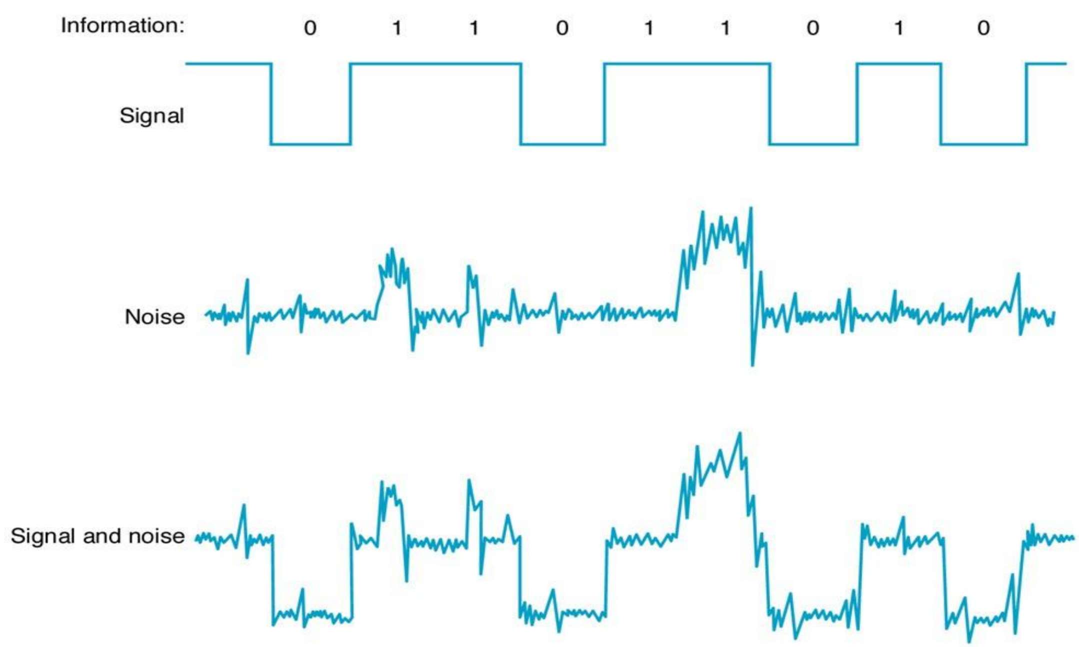
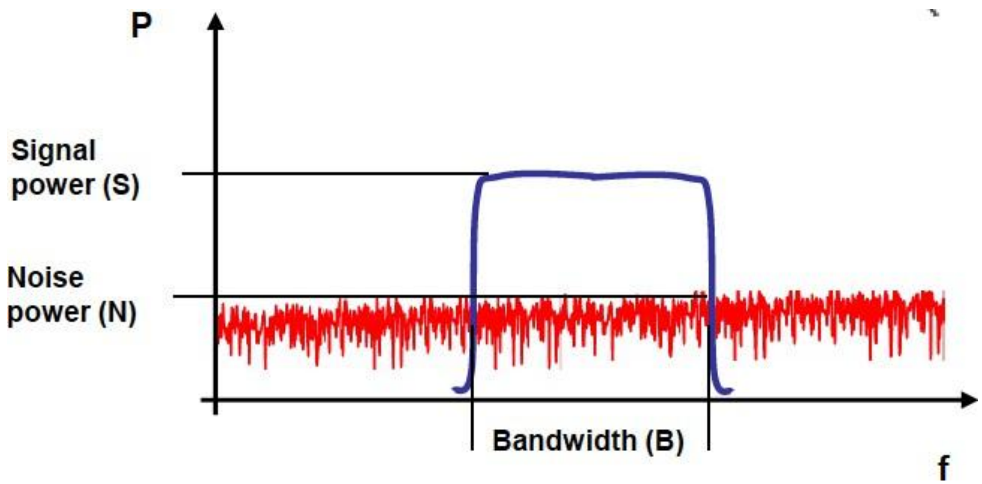
Noise Power, Noise Figure and Noise Temperature

Noise

- "Any unwanted input" - UNDESIRABLE portion of an electrical signal
- Limits systems ability to process weak signals



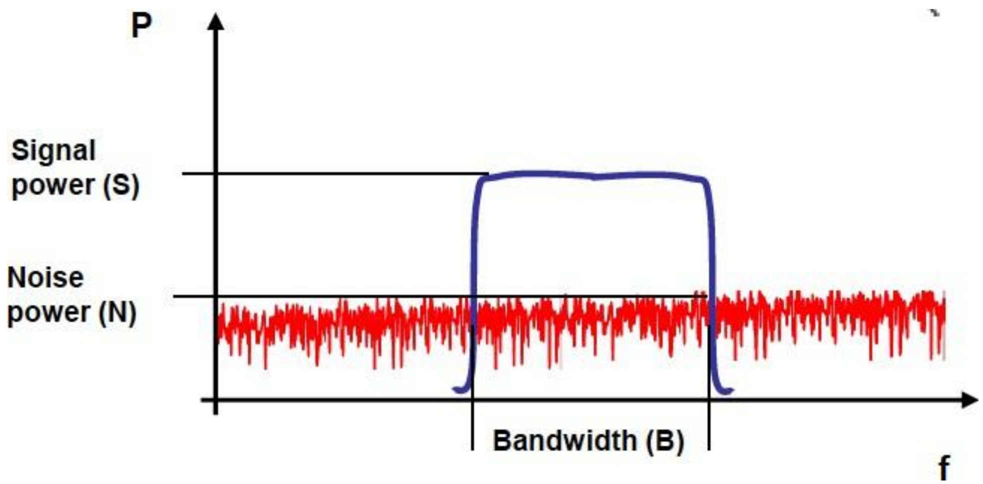
Noise Power



- Most of input noise = Thermal Noise
- Noise power $\boxed{N_p = k_B T\, B}$

k_B = Boltzmann's constant 1.38×10^{-23} J/K
T = Absolute temperature of device
B = Circuit bandwidth

Noise Power

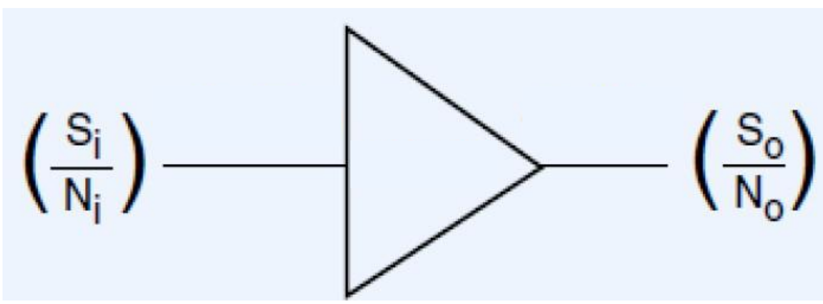


- Signal to Noise Ratio (SNR)

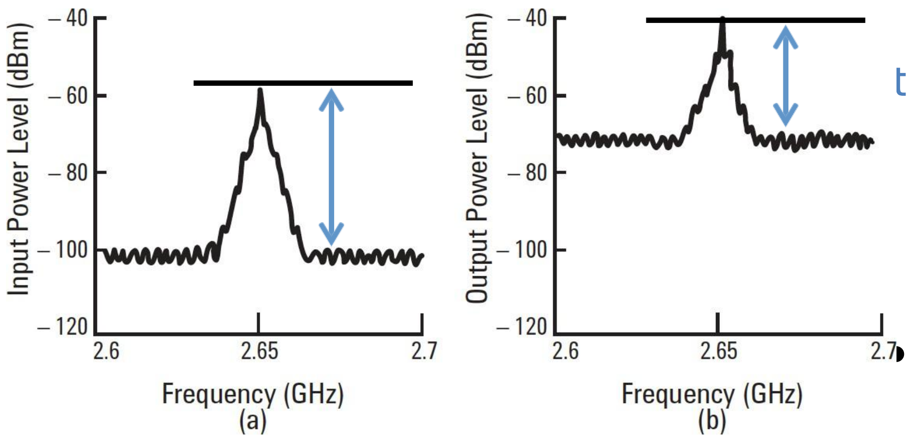
$$\boxed{SNR = \frac{S(f)}{N(f)} = \frac{average - signal - power}{average - noise - power}}$$

Noise Figure

- Noise Figure



- Noise figure represents the degradation in signal/noise ratio as the signal passes through a device.



tput

$$\boxed{F = \frac{S_i/N_i}{S_o/N_o}}$$

- F is always greater than 1.

Noise Figure

- Noise Figure

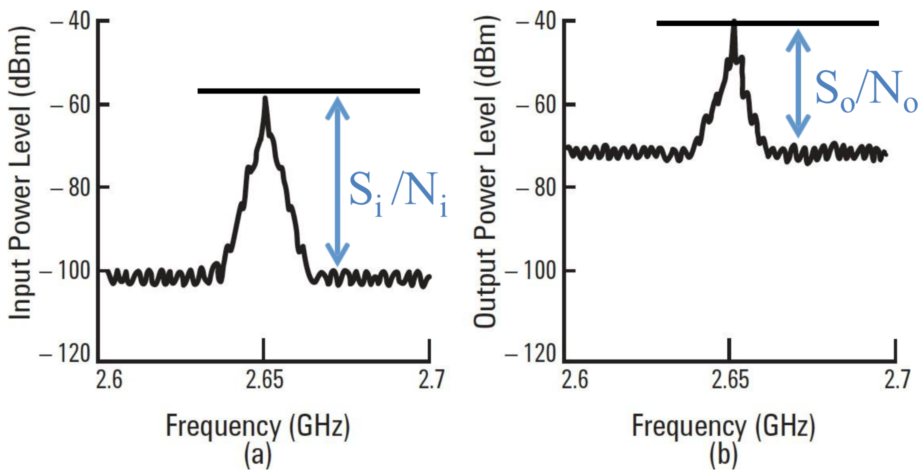
Noise Factor

$$F = \frac{S_i/N_i}{S_o/N_o}$$

Modern usage of “noise figure” usually is reserved for the quantity NF, expressed in dB units:

$$\boxed{NF = 10 \log_{10} F \quad [\text{dB}]}$$

$$\mathbf{NF = (Si/Ni)_{dB} - (So/No)_{dB}}$$



$(Si/Ni)_{dB} = 40$ dB
$(So/No)_{dB\,=} = 30$ dB

Noise Figure = 10 dB

Noise Temperature

- Comes from the random motion of electrons
  → Thermal Noise
- Convenient! Common basis for measuring random electrical noise from any source

- Relation with Noise Figure

$$\boxed{T_e = T_o (F - 1)}$$

T_e : The effective noise temperature of device
T_0 : a reference temperature 290K (room temperature)

Summary

- Noise Power
  - The magnitude of Noise

$$\boxed{N_p = k_B T B}$$

- Noise Figure
  - Noise Factor

$$\boxed{F = \frac{S_i/N_i}{S_o/N_o}}$$

  - Noise Figure : the degradation of SNR

$$\boxed{NF = 10 \log_{10} F \quad [\mathrm{dB}]}$$

- Noise Temperature
  - Basic tool of measuring any kind of noise
  - Relation with Noise Factor

$$\boxed{T_e = T_o (F - 1)}$$

Quadrature Representation of Narrowband Noise

When noise is concentrated around a carrier frequency ω_c, it can be expressed in terms of two **low-pass Gaussian processes**:

$$n(t) = n_I(t)\cos(\omega_c t) - n_Q(t)\sin(\omega_c t)$$

- $n_I(t)$: **In-phase component** (I-channel).
- $n_Q(t)$: **Quadrature component** (Q-channel).

This representation is extremely useful in communication systems because it allows us to treat narrowband noise as if it were a baseband signal with two orthogonal components.

Properties of Quadrature Noise Representation

- **Gaussian nature:** Both $n_I(t)$and $n_Q(t)$are Gaussian random processes.
- **Uncorrelated components:** $n_I(t)$and $n_Q(t)$are statistically independent (uncorrelated).
- **Equal variance:** Each component has the same variance, equal to half the total noise power.
- **Stationarity:** Both processes are wide-sense stationary.
- **Symmetry:** The power spectral density (PSD) of narrowband noise is symmetric around the carrier frequency.
- **Envelope representation:** The noise envelope can be expressed as:

$$A(t) = \sqrt{n_I^2(t) + n_Q^2(t)}$$

which follows a Rayleigh distribution.

- **Phase representation:** The instantaneous phase:

$$\phi(t) = \tan^{-1}\left(\frac{n_Q(t)}{n_I(t)}\right)$$